Endocrine disrupting chemicals in New Orleans surface waters and Mississippi Sound sediments†

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Abstract

Endocrine disrupting compounds (EDCs), represented by steroid hormones, organochlorine pesticides (OCPs), polychlorinated biphenyls (PCBs), and bisphenol A have been determined in four sediment cores from the Gulf of Mexico, from New Orleans surface water (Lake Pontchartrain and Mississippi river), and from the influent and effluent of a New Orleans municipal sewage treatment plant. During the five-month monitoring of selected EDCs in the Mississippi river (MR) and Lake Pontchartrain (LP) in 2008, 21 of 29 OCPs in MR and 17 of 29 OCPs in LP were detected; bisphenol A was detected in all of the samples. Steroid hormones (estrone, 17β-estradiol and 17α-ethinylestradiol) were detected occasionally. Total EDC (OCPs + PCBs + steroid hormones + bisphenol A) concentrations in the two surface water samples were found to vary from 148 to 1112 ng L^{-1}. Strong correlation of the distribution of total OCPs, total PCBs and total EDCs between solid and water phases was found in LP, while moderate or no correlation existed in MR. OCPs, PCBs, steroid hormones, and bisphenol A were all detected in the ocean sediments, and total EDCs were measured in the range of 77 to 1796 ng g^{-1} dry sediment weight. The EDCs were also found in untreated and treated municipal sewage samples with a removal efficiency of 83% for OCPs but no removal efficiency for 17α-ethinylestradiol.

Introduction

Endocrine disrupting compounds (EDCs) are exogenous substances or mixtures that alter function(s) of the endocrine system and consequently cause adverse health effects in an intact organism or its progeny or (sub)populations. EDCs thus interfere with the normal functioning of hormonal receptors that mediate endogenous hormones, causing reduced fertility, skewed sex ratios, abnormalities in both male and female reproductive tracts, early puberty, and compromised immune function, among other adverse outcomes.[1-4] Since 1993, when the term "endocrine disrupting chemicals" was first introduced,[5] hundreds of environmental pollutants have been reported as known or potential endocrine disruptors, including natural and synthetic hormones,[6,7] PCBs,[8] pesticides,[9] and industrial chemicals

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such as the ubiquitous bisphenol A.[10] These EDCs have been detected in a variety of surface and ground water bodies including rivers, lakes, and oceans.[11] They also occur in different animal and plant food products.[12] EDCs may be effective in biological systems at extremely low concentrations, thus raising the risk factors in wildlife as well as in humans. The detection of many EDCs, such as organochlorine insecticides and the plasticizer bisphenol A, in the blood of the general population in the US is disturbing,[10,13] especially when EDCs occur at blood levels several times greater than that of estradiol in premenopausal women and about the same as that of testosterone in men.[14] The full extent, magnitude, and ramifications of their presence in the aquatic environment are largely unknown.

As a major coastal region in the US, the lower Mississippi River/Gulf of Mexico (MR/GoM) estuary receives sewage discharges and agricultural run-offs from 10 states along the river course. In this study we report the distribution of EDCs in the aquatic environment of the Mississippi river delta. The surveyed EDCs are represented by three steroid hormones, bisphenol A, 29 organochlorine pesticides, and 22 polychlorinated biphenyls. Water samples from Lake Pontchartrain and the Mississippi river were collected periodically and their EDC concentrations were analyzed. Marine sediment cores collected from the Gulf of Mexico were examined for contamination by the selected EDCs. To gain a better understanding of the source and fate of EDCs in the environment, sewage influents and effluents at a New Orleans sewage treatment plant were also analyzed to determine the concentrations of these EDCs. Together, these results provide a baseline map of the distribution of environmental EDCs in New Orleans surface water and in the sediments in the Mississippi Sound of the Gulf of Mexico.

Experimental

Materials and regents

Standard pesticide mixtures, N,O-bis(trimethylsilyl)trifluoroacetamide (BSTFA), bisphenol A, three hormone standards, 2,4,5,6-tetrachloro-m-xylene, 2,3-dichlorophenoxyacetic acid, 4,4′-difluorobiphenyl, and decachlorobiphenyl were obtained from Ultra Scientific (North Kingstown, RI, USA). All other reagents and standards were purchased from Fisher Scientific (Fair Lawn, NJ, USA). C_{18} and SDB-XC extraction disks were purchased from 3M Empore (St. Paul, MN, USA). Glass fiber filters (0.2–0.6 μm) were purchased from Millipore Corporation (Bedford, MA, USA). A Chromtech (Apple Valley, MN, USA) manifold station and standard filter apparatus was used for all sample extractions and elutions. A Supelco (Bellefonte, PA, USA) Visiprep SPE vacuum manifold was used for concentration and purification of solvent extracts. A Fisher 100 Model ultrasonicator was used for the extraction of suspended solids.

Sample collection

The surface water and sewage water sampling sites are illustrated in Fig. 1. Water samples from the Mississippi river (MR) and Lake Pontchartrain (LP) were taken monthly from May through to September of 2008. The samples were collected in pre-cleaned 4 L amber glass containers, acidified in the lab, and stored at 4 °C before filtration and extraction. Influent and effluent sewage samples were obtained from the New Orleans East sewage treatment plant with permission. Treated sewage underwent primary and secondary treatment followed by disinfection. Sediment cores were collected using a modified boxcore collector on-board a ship at four sites (Fig. 2). The sites selected were North of Horn Island (HI) (30° 16.0′ N, 88° 46.0′ W), Henderson Point (HP) (30° 18.0′ N, 89° 18.0′ W), the mouth of Pearl River (P) (30° 10.0′ N, 89° 31.0′ W), and South of Bay St. Louis (SB) (30° 14.0′N, 89° 20.0′W). Sediment cores were sectioned into slices 1–3 cm thick, air-dried, homogenized, and stored at −20 °C before analysis.

Sample preparation

The multi-step sample preparation procedure is shown in the flowchart of Fig. 3 where all samples were processed and analyzed in duplicate. For surface water and sewage samples, two Empore disks, C_{18} and SDB-XC with a 0.2–0.6 mm glass fiber filter were fitted together inside a vacuum extraction manifold. These disks were consecutively conditioned under vacuum using dichloromethane (10 mL), acetone (10 mL), and methanol (10 mL), followed by 10 mL water to avoid dryness. The acidified water samples were transferred to a reservoir, and passed through the fiber filter/C_{18}/SDB-XC disks under vacuum at a flowrate between 10–15 mL min^{-1}. The filtered water was discarded and the disks were subjected to vacuum conditions for an additional 20 min to remove as much water as possible. After drying, the glass fiber filter was carefully separated from the C_{18}/SDB-XC disks using Teflon®-lined tweezers; the C_{18}/SDB-XC disks were consecutively eluted with methanol (10 mL), acetone (10 mL), and dichloromethane (10 mL). All eluents were collected in a 60 ml tube for subsequent clean-up procedures. The glass fiber filters were placed in a 60 mL glass vial containing 10 mL of methanol and sonicated for 30 min. The methanol extract was transferred to another 60 mL vial, and the filters were extracted consecutively with acetone (10 mL) and dichloromethane (10 mL). The extracts were combined and treated in the next clean-up procedure. The combined extracts were dried by anhydrous Na_2SO_4 and their volumes were reduced to 1 mL under a nitrogen stream. The extracts were divided into two equal aliquots: one for pesticides and PCBs quantification and the other for hormone analysis. The first aliquot was cleaned up with silica gel and concentrated to 500 μL for direct analysis by GC-MS. The second aliquot was reduced to dryness and derivatized with BSTFA (*N,O*-bis(trimethylsilyl)trifluoroacetamide) for 30 min at 80 °C and analyzed by GC-MS.

For sediment samples, aliquots of 5 g air-dried sediment were extracted with mixed methylene chloride-acetone solvent in an accelerated solvent extractor (Dionex ASE-200). The extracts were first evaporated to approximately 2 mL under a nitrogen stream and were then loaded onto the top of the solid phase extraction cartridges containing 2 g of silica gel. Analytes were eluted from the column with 10 mL methylene chloride using a Visiprep SPE Vacuum Manifold (Supelco, Bellefonte, PA), dried with Na_2SO_4, concentrated to 1 mL and divided into two equal aliquots. For pesticides and PCBs analysis, internal standards were added to one aliquot followed by GC-MS analysis. For hormone analysis, the other aliquot was reduced until dry and derivatized with BSTFA for 30 min at 80 °C and analyzed by GC-MS. All evaporation and clean-up procedures were carried out in a fume hood to minimize organic solvent vapor contamination in the laboratory.

To determine the recoveries of EDCs, two matrices were used for spiking. For recovery tests for the surface water and sewage samples, one liter of MR water was spiked with EDCs using the working solutions to yield fortified water samples containing 10–70 ng L^{-1} EDCs. The fortified samples were shaken vigorously to enable sufficient distribution of the target compounds within the sample matrix. The solvent extraction took place the next day (16 h later) to ensure dissolution and adsorption of target compounds in the water phase and onto the suspended solid particles. For the recovery test in the sediments, 1.0 g aliquots of air dried sediment was fortified with 20 μL standard analytes solution to give EDC concentrations of 2.0 μg kg^{-1} of dried sediments for each analyte. The fortified sample aliquots ($n = 3$) were then mixed with 1.0 g anhydrous Na_2SO_4 before they were transferred into the Accelerated Solvent Extraction (ASE) cells. The recoveries of EDCs were determined by using the EDC peak areas attributed to spiked quantities and are summarized in Table 1.

Calibration, limit of detection, limit of quantitation, quality assurance and quality control (QA/QC)

The calibration standard solutions were prepared by diluting the mixture to concentrations ranging from 0.1 µg mL^{-1} to 5.0 mg mL^{-1} with methylene chloride. 2,4,5,6-tetrachloro-*m*-xylene was used as a surrogate for pesticides and PCBs, and 2,3-dichlorophenoxyacetic acid was used as a surrogate for BPA and hormones. 4,4′-difluorobiphenyl and decachlorobiphenyl were used as the internal standards that were added to the final extracts prior to GC-MS analysis.

Six-point calibrations were performed monthly using serially diluted standards containing all of the EDCs. Instrument calibration was done by tuning the MS at a 48 to 72 h interval to ensure proper instrumental performance. Method detection limits were determined as the concentrations of analytes in a sample that give rise to peaks with a minimal signal to noise ratio (*S/N*) of 3. Limit of quantitation for each analyte was determined as its concentration that yields a peak with 10 times that of average noise level. The LOQ for each EDC was used as the final reporting limit of the compound. Analyte identification was confirmed by the GC retention time and qualifier ions as detailed in Supplementary Table 1, see ESI†. Ion ratios were further monitored to distinguish interferences from the target compounds in field samples. Only peaks with acceptable qualifier/target ion ratios were integrated for quantification.

Every batch of samples had one field blank and one laboratory blank as a quality control measure. The field blank was taken by simulating a collection of field samples. 4 liters of HPLC grade water was brought to the sampling site using a 4 L ashed bottle, and transferred into another 4 L bottle, then transported back to laboratory along with field samples. The lab blank included 1 liter of HPLC grade water. The lab blank and field blank were processed in the same way as the field samples in the laboratory. A lab blank, a field blank, solvent blanks, and a standard mixture were run in sequence to check contamination and instrument conditions. To avoid contamination during sampling and sample preparation, sampling bottles and all glassware used for sample collection and preparation were cleaned by washing with detergent, rinsed with deionized water, and ashed in a muffle furnace at 550 °C for more than 4 h. All laboratory materials were either made of glass or Teflon® to avoid sample contamination. Teflon® containers were cleaned in the same manner as glassware, but without the ashing step.

Quantitative analysis of EDCs

An Agilent 6890N gas chromatograph (GC) equipped with a 5973N mass selective detector (Agilent Technologies, Palo Alto, CA) was used for the quantitative determination of EDCs. The GC column used was an HP-5MS, crosslinked 5% phenyl methyl siloxane capillary column, 30 m × 0.25 µm id, with film thickness of 0.25 mm. The GC-MS was operated under the following conditions. The temperature of the injection port and the detector was held at 290 °C. The oven temperature was set at 40 °C initially (1 min hold), increased to 250 °C at 12 °C min^{-1}, and then to 310 °C at a rate of 5 °C min^{-1} (3 min hold). Thetemperatures of the ion source and the quadrupole mass analyzer were kept at 250 and 100 °C, respectively. Helium gas was used as the carrier gas at a constant flow rate of 0.8 mL min^{-1}. An automatic sample injector (HP 6890) was used to introduce 1.0 mL of each sample extract in an intermittent standard injection sequence. The retention time of each EDC was determined by injecting individual EDC solutions under constant GC-MS instrumental conditions. The SIM mode (selected ion monitoring) was then used for quantification in which three ions were selected for calculating the chromatographic peak

areas. The relative peak ratio of the peak area of each EDC to that of the selected internal standard was used to plot against the concentration of the corresponding EDC in serially diluted standard solutions. Thus a calibration curve was obtained for each EDC for subsequent quantitative analysis of liquid and solid samples. A total ion chromatogram (TIC) of a standard pesticide solution and a TIC of a surface water sample extract are illustrated in Fig. 4.

Statistical analysis

To analyze the relationships among EDCs detected at the disparate collection sites, the data was pooled using the mean values for the Gulf sediments, the totals by month for MR and LP, and the total sewage influent and effluent values. This comprised a total of 16 samples. 5 of the 29 organochlorine pesticides (1,2-dibromo-3-chloropropane, hexachlorobenzene, chlordane, endosulfan sulfate, and methoxychlor) were detected in 2 or fewer samples, and these were removed from the dataset for the purposes of this analysis. For the remaining EDCs, the measurements were log-transformed to reduce skewness and ND values were replaced by 0s. Hierarchical clustering was applied to both the chemicals and to the sites, using the Gower dissimilarity metric to compute pairwise distances and Ward's minimum variance method for cluster agglomeration. All analyses were performed using the R software package, version 2.14.[15]

Results and discussion

Data obtained by the survey of Mississippi river, Lake Pontchartrain, and 4 marine sediment sites is presented in Tables 2-5. The EDC concentrations in MR and LP were determined for a five-month sampling period from May 2008 through September 2008. For the water samples, total EDC concentrations are the sum of EDC concentrations in the liquid phase and the suspended solid phase determined separately. Of the 29 pesticides selected for measurement in MR samples, only two (dieldrin and chlorobenzilate) were detected in all samples (100% occurrence); 2 were detected in 4 out of 5 water samples (80% occurrence), 4 were detected in 3 samples (60% occurrence), with the rest of pesticides detected twice or fewer in five samples (less than 40% occurrence). Concentrations of individual pesticides ranged from non detectable to 117 ng L^{-1}, while the total pesticide concentrations detected were up to 570 ng L^{-1}. In Lake Pontchartrain, dieldrin, chlorobenzilate, and endrinaldehyde were the most frequently detected pesticides (4 out of 5 samples, 80% occurrence), followed by delta-BHC, heptachlor, endosulfan I, and endrin keton (detected in 3 out of 5 samples, 60% occurrence). The total pesticide levels in Lake Pontchartrain ranged from 68 ng L^{-1} to 364 ng L^{-1}. The consistent detection and relatively high concentration of dieldrin in both MS and LP reflects its widespread use in the recent past in the United States. Dieldrin has been widely detected in surface waters around the world, with concentration ranges comparable to this study.[16-18] On the other hand, the frequent occurrence of chlorobenzilate in New Orleans surface water was surprising because it is practically insoluble in water and has been rarely detected since its ban in 1979 in the United States.[19] However, the use of chlorobenzilate in citrus cultivation continued until 1999. It is possible that abundant citrus farms in Louisiana's coastal areas, including New Orleans, have contributed to the ubiquitous presence of chlorobenzilate in surface water and marine sediments.

Of the 27 PCB congeners monitored, PCB #5, 101, 201, and the sum of 31, 50, 77 were the most frequently detected. Total PCB concentrations varied from 86 to 254 ng L^{-1} in the Mississippi river. In comparison, Lake Pontchartrain waters were found to contain higher concentrations of PCBs (134 to 728 ng L^{-1}). These levels are similar to those reported for surface waters in the US and elsewhere.[20,21] The relatively higher PCB concentrations in LP than in the MR may suggest that in the absence of point contamination source, atmospheric deposition is likely the main contribution to the bulk of PCBs in hydrosphere.[22]

Other EDCs determined include bisphenol A and three hormones during the sampling period. BPA was detected in both liquid and solid phase in all MR and LP water samples at concentrations between 0.32–57 ng L^{-1}, indicating the ubiquitous nature of its contamination in surface water. Estrone was detected in three out of the five samples in MR and LP at a concentration range of 0.43–3.38 ng L^{-1}. 17β-estradiol was detected twice in the river but three times in the lake with concentrations in the low ng L^{-1} range. The synthetic hormone, 17α-ethinylestradiol (EE2) was not detected in the MR but was detected in three out of five LP water samples at around 2 ng L^{-1}. EE2 has been detected at higher concentration and frequency in river waters of several Asian countries.[23]

Characterization of the distribution of EDCs between solid and water phases in MR and LP is important to understand their fate, transportation and monitoring in New Orleans surface waters.[24] Correlations between their concentrations absorbed in solid (C_s) and dissolved in water (C_w) were calculated for total OCPs, total PCBs and total EDCs, respectively as shown in Fig. 5 and 6. Strong correlation was found for the total OCPs ($R^2 = 0.973$), total PCBs ($R^2 = 0.984$) and total EDCs ($R^2 = 0.993$) in LP, while moderate correlation for total OCPs ($R^2 = 0.883$) and total EDCs ($R^2 = 0.496$), and no correlation for total PCBs ($R^2 = 0.00770$) were found in the MR. In a previous study of contamination in the MR,[24] the ratios of C_s/C_w for total PCBs indicated similar degrees of correlation between suspended solidconcentration (SS) and the concentration dissolved in water. It is interesting to note that for all groups of EDCs, LP samples consistently showed a higher degree of correlation between the solid and the liquid phase concentrations. It is likely that the EDCs may have had a longer time to reach equilibrium between the two phases in the lake than in the more dynamic water body of the river.

In the four sediment cores collected from the Mississippi Sound in the Gulf of Mexico, concentrations of individual pesticides were found to vary from non detectable to over 800 ng g^{-1} dry sediment wt. Notably, endrin and its two most abundant metabolites, endrin ketone and endrin aldehyde were detected at mean concentrations up to 165 ng g^{-1}, 87 ng g^{-1}, and 302 ng g^{-1}, respectively. These levels are significantly higher than reported in sediment samples such as those from Portuguese coastal areas.[25] Other OCPs detected at high frequency and elevated concentrations include endosulfan I, dieldrin, aldrin, α, β, δ-BHC, and chlorobenzilate. The OCP levels determined in the Gulf of Mexico sediments are significantly higher than reported in some studies in marine sediments elsewhere,[26] but comparable to others.[27] Total PCBs in sediments were found at concentrations ranging from non detectable to 32 ng g^{-1}, similar to levels measured in marine sediments in northern Morocco,[28] in the Haihe estuary area in China, and in some river sediments.[29] Bisphenol A was detected at high frequency but relatively low concentration (0.4-2.99 ng g^{-1}), whereas the two natural hormones, estrone and 17β-estradiol were detected infrequently at very low concentrations (Table 3). The synthetic estrogen, 17α-ethinylestradiol was found more frequently than the natural estrogens at slightly higher concentrations. Overall, these estrogenic compounds in the Gulf of Mexico sediments were present at lower concentrations than in other marine environments.[30,31] Notably, the total EDC concentrations appeared to correlate with the sediment levels of PAHs, another group of organic pollutants that we measured in the same sediment extracts. Thus, the total PAHs concentrations in sediments were found at 2591 ng g^{-1} (South of Bay St. Louis, total EDCs: 267 ng g^{-1}), 5774 ng g^{-1} (Pearl River Mouth, total EDCs: 908 ng g^{-1}), 1246 ng g^{-1} (Henderson Point, EDcs: 213 ng g^{-1}), and 7400 ng g^{-1} (Horn Island, total EDCs: 1166 ng g^{-1}). It is well documented that organic carbon is closely associated with PAH levels,[32,33] therefore the close correlation between total PAHs and total EDCs can be considered as evidence that EDCs also tend to associate with organic carbon contents in marine sediments.

The occurrence and concentrations of these endocrine disrupting compounds were also examined in the influent and effluent samples from a major New Orleans sewage treatment plant. Results are summarized in Table 4 where the concentrations of total OCPs, total PCBs, bisphenol A, and three hormones are determined in municipal sewage before and after treatment in a New Orleans East sewage treatment plant. Organochlorine pesticides were detected at significant concentration levels reaching 960 ng L^{-1} in raw sewage and remaining at 624 ng L^{-1} in treated sewage. Few reports are available that measure OCP concentrations in municipal wastewater, but there is abundant data of OCP residues in sewage sludge which vary widely. For example, a mean concentration of 500 µg kg^{-1} diedrin has been reported in sewage sludge in the UK.[34] This suggests that the conventional sewage treatment method (activated sludge and chlorination) may not be effective in removing trace organic pollutants such as OCPs. PCB concentrations were determined at much lower levels in sewage. Total PCBs were found at 64 ng L^{-1} in untreated sewage and 30 ng L^{-1} in treated waste water with a 52% removal rate. Bisphenol A concentration in influent sewage was measured at 203 ng L^{-1} in the liquid phase and 131 ng L^{-1} in the particulate phase. The removal of BPA reached 83%, resulting in a residual concentration of 55 ng L^{-1} in the effluent. The level and removal efficiency of BPA in New Orleans sewage was similar to that in sewage samples analyzed elsewhere.[35] Of the three hormones examined in the sewage waters, estrone was found at the highest concentration (359 ng L^{-1}), followed by 17β-estradiol with a concentration of 155 ng L^{-1}. With removal efficiencies of 69% and 65% respectively, the residual level of estrone and 17β-estradiol was still significant in the treated sewage. The synthetic estrogen, 17α-ethinylestradiol was detected at a much lower level (4.6 ng L^{-1}) in raw sewage. Its presence in treated sewage at essentially the same concentration indicates that there was no removal efficiency for this compound at low ng L^{-1} concentrations.

To identify possible correlations among EDCs in disparate sampling sites and sample types, we have performed hierarchical clustering analysis for the most frequently detected EDCs. The results are shown in Fig. 7. The sites were clustered into four well-separated groups. The first included measurements for sewage influent and effluent, the second included measurements for MR and LP in August and September, the third included measurements for MR and LP in May, June, and July, and the fourth included the measurements for sediment at the four Gulf sites. Notably, concentrations of EDCs for May, June and July in both MR and LP were much higher for endrin and related chemicals than in August and September, and most of the organochlorine pesticides detected in MR and LP were also present in high concentrations in the Gulf sediment. This trend may reflect the higher usage of endrin/dieldrin and related OPCs to control insect pests of cotton, rice and sugar cane in the months leading to summer, and the fact that storm runoff typically peaks in July in the Southeast Louisiana area. On the other hand, bisphenol A and PCBs were present at higher levels in sewage, MR, and LP but were observed at very low levels in Gulf sediment. The relatively good solubility and short half life[36] of bisphenol A may in part explain its predominant presence in surface water. Another cluster included 17β-estradiol, estrone, and 17α-ethinylestradiol, three EDCs that were present at high levels in sewage influent and effluent but are either absent or at extremely low levels elsewhere, suggesting that sewage is the main source of these three estrogenic compounds.

Conclusion

The aim of this study was to survey the occurrence of selected EDCs in New Orleans surface waters and sediments from the Gulf of Mexico, represented by 29 OCPs, 27 PCB congeners, three steroid hormones (estrone, 17β-estradiol and 17α-ethinylestradiol) and bisphenol A. Most of the target analytes were detected at ppt level, showing their prevalence and persistence in the aquatic environment of this region. Each group of EDCs demonstrated

strong correlation in their distribution between suspended solid phase and water phase in Lake Pontchartrain. In comparison, the correlation was more moderate in Mississippi River samples. Low removal rate of total EDCs (53%) in a New Orleans secondary sewage treatment plant further demonstrated relatively poor biodegradability of the EDCs, contributing to their persistence in the aquatic environment.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

References

1. Maffini MV, Rubin BS, Sonnenschein C, Soto AM. Mol. Cell. Endocrinol. 2006; 254-255:179–186. [PubMed: 16781053]

2. Rasier G, Toppari J, Parent AS, Bourguignon JP. Mol. Cell. Endocrinol. 2006; 254-255:187–201. [PubMed: 16720078]

3. Toppari J. Sexual Development. 2008; 2:260–267. [PubMed: 18987500]

4. Swedenborg E, Ruegg J, M€akel€a €S, Pongratz I. J. Mol. Endocrinol. 2009; 43:1–10. [PubMed: 19211731]

5. Colborn T, vom Saal FS, Soto AM. Environ. Health Perspect. 1993; 101:378–384. [PubMed: 8080506]

6. Kortenkamp A. Environ. Health Perspect. 2007; 115(Suppl. 1):98–105. [PubMed: 18174957]

7. Harries JE, Sheahan DA, Jobling S, Matthiessen P, Neall P, Sumpter JP, Tylor T, Zaman N. Environ. Toxicol. Chem. 1997; 16:534–542.

8. Longnecker MP, Rogan WJ, Lucier G. Annu. Rev. Public Health. 1997; 18:211–244. [PubMed: 9143718]

9. McKinlay R, Plant JA, Bell JN, Voulvoulis N. Environ. Int. 2008; 34(2):168–183. [PubMed: 17881056]

10. Vandenberg LN, Hauser R, Marcus M, Olea N, Welshons WV. Reprod. Toxicol. 2007; 24:139–177. [PubMed: 17825522]

11. Kolpin DW, Furlong ET, Meyer MT, Thurman EM, Zaugg SD, Barber LB, Buxton HT. Environ. Sci. Technol. 2002; 36:1202–1211. [PubMed: 11944670]

12. Nilsson R. Toxicol. Pathol. 2000; 28:420–431. [PubMed: 10862560]

13. Charlier CJ, Plomteux GJ. Clin. Chem. Lab. Med. 2002; 40:361–364. [PubMed: 12059076]

14. Stehr PA. J. Toxicol. Environ. Health. 1989; 27:405–421. [PubMed: 2760935]

15. R Development Core Team. R: A language and environment for statistical computing. R Foundation for Statistical Computing; Vienna, Austria: 2011. ISBN 3-900051-07-0, URL http://www.R-project.org/

16. Papadopoulou-Mourkidou, E. Ministry of Agriculture. Thessaloniki, Greece: 2002.

17. Fatoki OS, Awofolu OR. J. Environ. Sci. Health, Part B. 2004; 39:101–114.

18. Xue N, Xu X, Jin Z. Chemosphere. 2005; 61:1594–1606. [PubMed: 15982717]

19. Howard, PH., editor. Handbook of Environmental Fate and Exposure Data for Organic Chemicals, Vol. III: Pesticides. Lewis Publishers; Chelsea, MI: 1989.

20. Palmer PM, Wilson LR, Casey AC, Wagner RE. Environ. Monit. Assess. 2011; 175:487–99. [PubMed: 20556645]

21. Garc ia-Flor N, Dachs J, Bayona JM, Albaig es J. Chemosphere. 2009; 75:1144–1152. [PubMed: 19356787]

22. Kuzyk ZZ, Macdonald RW, Johannessen SC, Stern GA. Environ. Sci. Technol. 2010; 44:3280–3285. [PubMed: 20392087]

23. Duong CN, Ra JS, Cho J, Kim SD, Choi HK, Park JH, Kim KW, Inam E, Kim SD. Chemosphere. 2010; 78:286–293. [PubMed: 19931116]

24. Zhang S, Zhang Q, Darisaw S, Ehie O, Wang G. Chemosphere. 2007; 66:1057–1069. [PubMed: 16884762]

25. Carvalho PN, Rodrigues PN, Basto MC, Vasconcelos MT. Chemosphere. 2009; 75:595–600. [PubMed: 19243810]

26. Hu L, Zhang G, Zheng B, Qin Y, Lin T, Guo Z. Chemosphere. 2009; 77:663–672. [PubMed: 19709715]

27. Zhao L, Hou H, Zhou Y, Xue N, Li H, Li F. Chemosphere. 2010; 78:1285–1293. [PubMed: 20092869]

28. Piazza R, El Moumni B, Bellucci LG, Frignani M, Vecchiato M, Giuliani S, Romano S, Zangrando R, Gambaro A. Mar. Pollut. Bull. 2009; 58:431–438. [PubMed: 19111328]

29. Yang Z, Shen Z, Gao F, Tang Z, Niu J. Chemosphere. 2009; 74:1522–1530. [PubMed: 19108865]

30. Robinson BJ, Hui JP, Soo EC, Hellou J. Environ. Toxicol. Chem. 2009; 28:18–25. [PubMed: 18702564]

31. Zhang X, Li Q, Li G, Wang Z, Yan C. Mar. Pollut. Bull. 2009; 58:1210–1216. [PubMed: 19362723]

32. Hung CC, Gong GC, Ko FC, Chen HY, Hsu ML, Wu JM, Peng SC, Nan FH, Yeager KM, Santschi PH. Mar. Pollut. Bull. 2010; 60:1010–1017. [PubMed: 20206366]

33. Countway RE, Dickhut RM, Canuel EA. Org. Geochem. 2003; 34:209–224.

34. McIntyre A, Lester J. Water, Air, Soil Pollut. 1984; 23:397–415.

35. Stasinakis AS, Gatidou G, Mamais D, Thomaidis NS, Lekkas TD. Water Res. 2008; 42:1796–804. [PubMed: 18048079]

36. Klecka GM, Gonsior SJ, West RJ, Goodwin PA, Markham DA. Environ Toxicol Chem. 2001; 20:2725–2735. [PubMed: 11764155]

Environmental impact

Endocrine disrupting compounds (EDCs) in the environment can interfere with the normal functioning of hormonal receptors in organisms that mediate endogenous hormones, causing reduced fertility, skewed sex ratios, abnormalities in both male and female reproductive tracts, early puberty, and compromised immune function, among other adverse outcomes. The full extent, magnitude, and ramifications of their presence in the aquatic environment are largely unknown. This study provides a baseline map of distribution of environmental EDCs in New Orleans surface water and in sediments from the Mississippi Sound of the Gulf of Mexico.
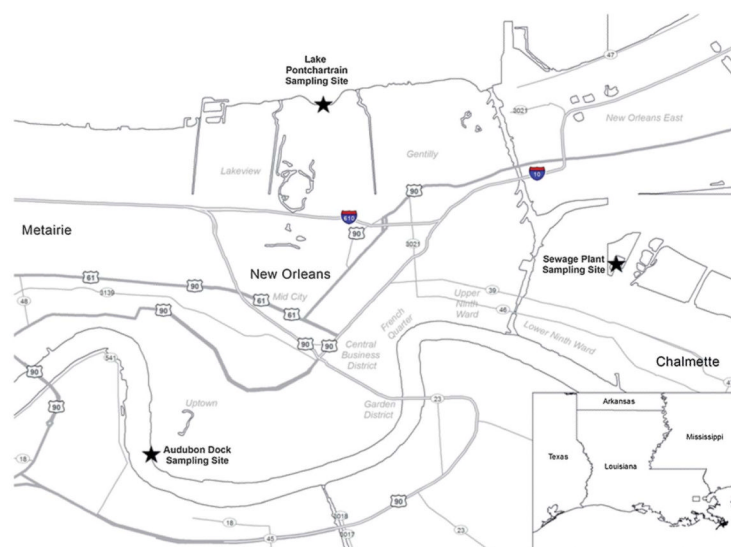
Fig. 1.
Sampling sites for New Orleans surface waters and sewage waters.

Fig. 2.
Sampling sites for Gulf of Mexico marine sediments.
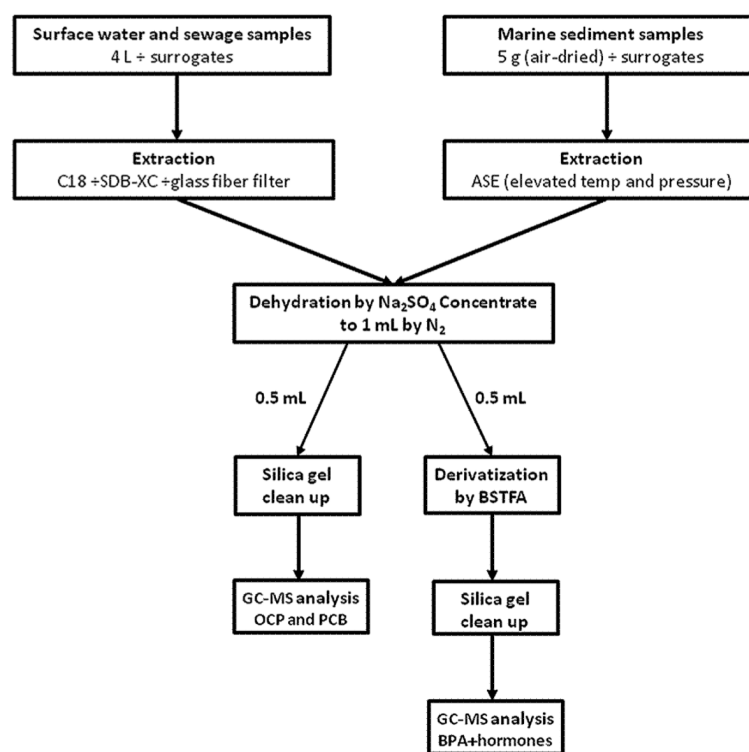
Fig. 3.
Flowchart of sample preparation and analysis for water and sediment samples.
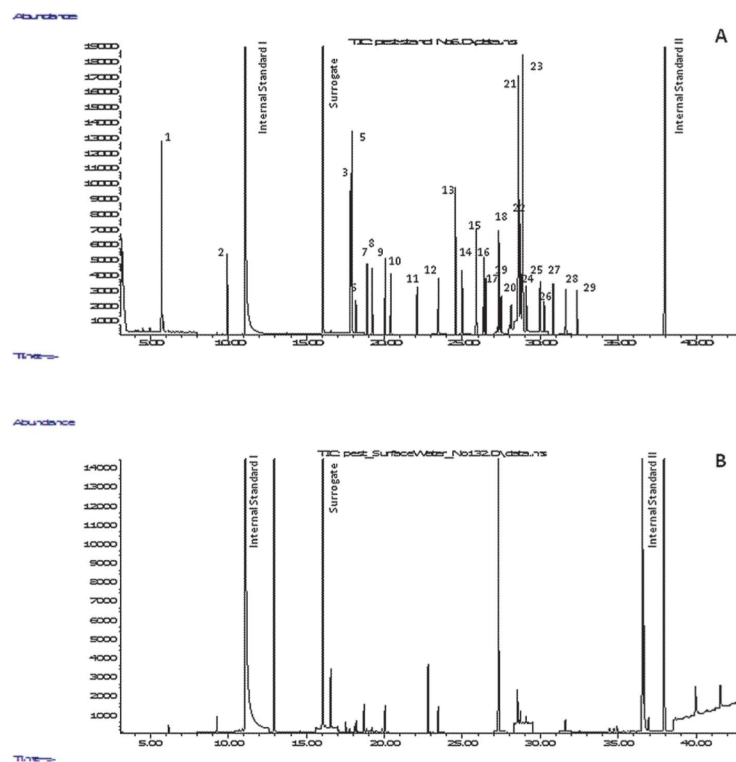
Fig. 4.
A. Chromatogram of 50 ng ml^{-1} pesticides standard solution containing compounds with peaks representing 1.1,2-dibromo-3-chloropropane; 2. hexachloropentadiene; 3. diallate; 4. alpha-BHC; 5. hexachlorobenzene; 6. gamma-BHC; 7. beta-BHC; 8. chlordene; 9. delta-BHC; 10. heptachlor; 11. aldrin; 12. isodrin; 13. heptachlor epoxide-isomer B; 14. gamma-chlordane; 15. endosulfan I; 16. alpha-chlordane; 17. *trans*-nonachlor; 18. 4,4′-DDE; 19. dieldrin; 20. endrin; 21. endosulfan II; 22. chlorobenzilate; 23. cis-nonachlor; 24. 4,4′-DDD; 25. endrin aldehyde; 26. endosulfan sulfate; 27. 4,4′-DDT; 28. endrin keton; 29. methoxychlor; Surrogate:2,4,5,6-tetrachloro-*m*-xylene; Internal standards: I. 4,4-difluorobiphenyl; II. decachlorobiphenyl. B. chromatogram of pesticides in a surface water sample. Surrogate: 2,4,5,6-tetrachloro-m-xylene; Internal standards: I. 4,4-difluorobiphenyl; II. decachlorobiphenyl.
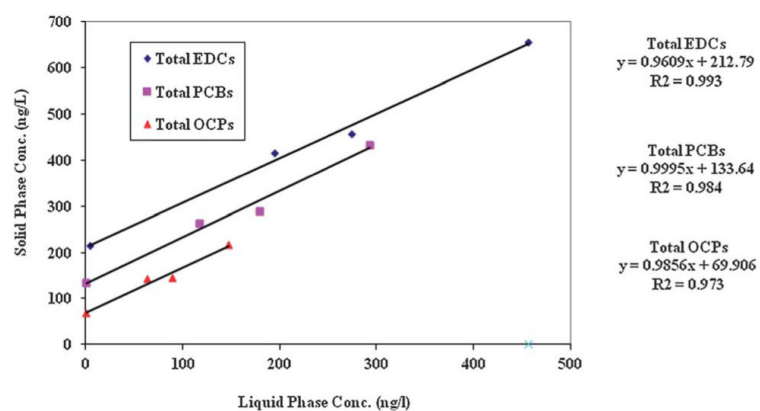
Fig. 5.
Correlation of total OCPs, total PCBs and total EDCs concentrations between liquid and solid phases in Lake Pontchartrain.
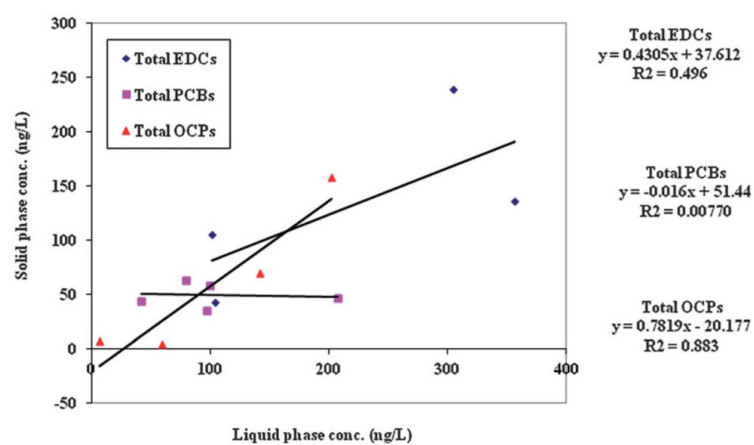
Fig. 6.
Correlation of total OCPs, total PCBs and total EDCs concentrations between liquid and solid phases in Mississippi River.
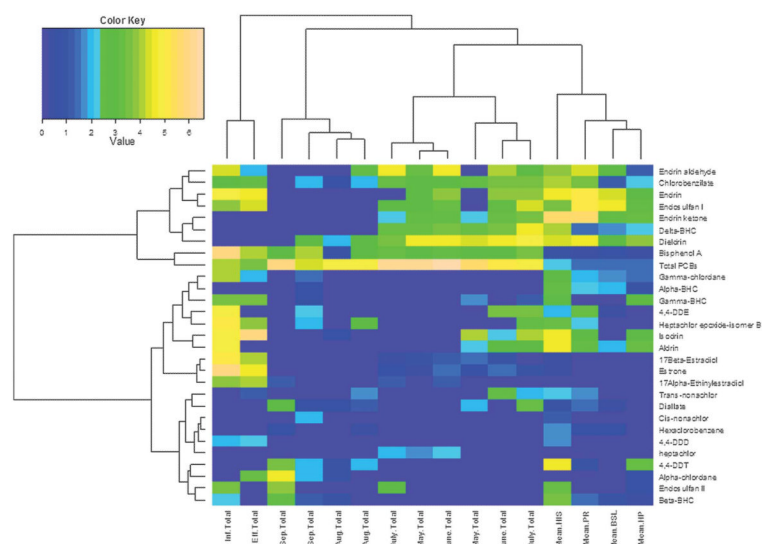
Fig. 7.
Heat map illustrating hierarchical clustering results for EDCs by type and location. EDC concentrations are presented on the logarithmic scale.

Table 1

Recovery and detection limits for individual EDCs monitored in this study

PCB congeners	Recovery in water (%)	CV (%)	Recovery in sediment (%)	CV (%)	LOD in water (ng L⁻¹)	LOD in sediment (µg kg⁻¹)	LOQ in water (ng L⁻¹)	LOQ in sediment (µg kg⁻¹)
1	57.9	7.1	87.3	10.2	2.13	0.03	4.67	0.08
5	59.2	7.5	86.3	5.3	2.46	0.03	5.36	0.09
18	56.6	12.8	85.1	4.0	1.12	0.02	2.64	0.04
29	76.5	7.8	63.3	4.9	1.64	0.04	3.87	0.09
315 077	62.2	7.0	91.8	12.8	1.28	0.04	3.42	0.10
104	87	16.7	90.6	6.9	1.15	0.02	2.58	0.05
44	80	17.8	97.3	12.3	2.34	0.04	5.68	0.08
66	101	11.9	93.6	12.9	1.05	0.03	2.49	0.07
101	88.9	7.4	88.2	8.0	2.88	0.02	6.46	0.05
87	89.3	8.3	92.4	11.9	2.61	0.02	5.74	0.06
110 154	96.3	10.7	94.0	4.9	1.17	0.04	3.49	0.10
151	92.6	11.1	89.6	8.2	2.35	0.04	5.31	0.08
188	107.1	15.4	86.6	8.5	2.18	0.03	4.64	0.07
153	101.5	18.6	92.5	5.0	2.43	0.04	5.63	0.08
141	107.1	17.9	89.3	6.9	2.12	0.03	4.72	0.10
137	106.1	15.1	98.7	5.1	2.33	0.04	5.82	0.10
187	98.9	11.5	91.9	5.9	2.14	0.04	5.55	0.10
183	100	6.7	104.1	6.4	2.48	0.04	6.43	0.11
201	105	7.7	95.6	11.9	3.51	0.04	7.21	0.11
180	111.1	9.5	95.5	8.3	2.27	0.04	4.97	0.10
170	110.1	6.3	105.1	16.8	2.39	0.05	5.45	0.11
208	117	13.9	106.4	8.8	2.62	0.04	6.24	0.12
206	108	16.1	91.3	10.5	2.37	0.04	6.11	0.10
Bisphenol A	84.5	11.7	87.6	13.7	0.30	0.15	1.03	0.26
Estrone	99.1	8.6	75.3	18.3	0.17	0.03	0.41	0.15
17β-Estradiol	85.2	9.6	71.5	12.2	0.28	0.05	0.54	0.29
17α-Ethinylestradiol	83.6	8.8	68.7	8.4	0.47	0.16	1.64	0.45

PCB congeners	Recovery in water (%)	CV (%)	Recovery in sediment (%)	CV (%)	LOD in water (ng L^{-1})	LOD in sediment (µg kg^{-1})	LOQ in water (ng L^{-1})	LOQ in sediment (µg kg^{-1})
Organochlorines								
1,2-Dibromo-3-chloropropane	57.7	14.9	96.7	13.2	0.86	0.16	1.51	0.47
Hexachloropentadiene	81.8	12.1	94.5	14.1	2.61	0.12	5.84	0.30
Diallate	70.5	18.7	84.9	12.7	0.94	0.09	3.22	0.31
Alpha-BHC	85.7	13.2	85.8	11.5	1.64	0.08	3.83	0.25
Hexachlorobenzene	64.9	15.4	91.4	17.6	0.81	0.08	1.84	0.30
Gamma-BHC	73.9	11.3	100.1	16.8	2.45	0.15	5.67	0.42
Beta-BHC	71.1	6.5	94.0	10.9	5.35	0.71	13.89	1.80
Chlordene	71.1	7.0	92.9	13.2	3.66	0.27	12.34	0.61
Delta-BHC	69.9	9.7	95.0	12.6	2.43	0.09	6.82	0.23
Heptachlor	85.6	17.1	94.3	11.7	2.89	0.12	6.31	0.36
Aldrin	67.1	7.3	94.6	8.2	2.51	0.09	5.95	0.19
Isodrin	67.0	12.4	98.2	8.4	1.79	0.11	4.67	0.24
Heptachlor epoxide-isomer B	75.3	18.3	96.2	8.2	1.43	0.15	3.64	0.35
Gamma-chlordane	90.5	7.9	86.7	12.5	1.64	0.28	3.98	0.62
Endosulfan I	104.9	12.3	104.2	14.2	3.24	0.16	7.52	1.20
Alpha-chlordane	93.0	17.0	101.5	9.4	2.38	0.57	6.83	1.24
Trans-nonachlor	85.6	20.1	110.4	9.5	2.73	0.64	7.02	1.58
4,4′-DDE	109.5	12.6	99.3	13.6	1.49	0.13	3.67	0.29
Dieldrin	106.1	15.4	108.5	9.2	1.38	0.12	4.06	0.34
Endrin	65.9	6.3	107.2	6.2	1.25	0.18	3.25	0.45
Endosulfan II	61.5	13.5	85.3	10.4	0.38	0.22	2.16	0.53
Chlorobenzilate	94.6	5.1	87.4	9.0	1.67	0.38	4.06	0.78
Cis-nonachlor	74.6	19.8	90.8	9.1	0.52	0.24	1.82	0.68
4,4′-DDD	73.2	21.6	105.1	18.7	2.22	0.05	5.09	0.17
Endrin aldehyde	68.5	14.3	72.9	11.1	3.68	0.51	8.05	1.23
Endosulfan sulfate	62.1	8.9	77.4	10.0	4.69	0.65	10.63	1.56
4,4′-DDT	80.5	8.0	80.1	16.5	1.63	0.06	4.29	0.16
Endrin ketone	81.2	14.3	88.4	9.7	1.12	0.08	3.06	0.23
Methoxychlor	78.7	17.5	87.2	5.4	1.47	0.12	4.27	0.27

Table 2

EDC Concentrations (ng L^{-1}) in Mississippi River Water from May 2008 to September 2008

	May-08			Jun-08			Jul-08			Aug-08			Sep-08			No of detect. in samples
	Liquid phase	Solid phase	Total	Liquid phase	Solid phase	Total	Liquid phase	Particle phase	Total	Liquid phase	Solid phase	Total	Liquid phase	Particle phase	Total	
1,2-Dibromo-3-Chloropropane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Hexachloropenta diene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Diallate	6.85	ND	6.85	ND	ND	ND	8.11	18.00	26.11	ND	ND	ND	ND	ND	ND	2
Alpha-BHC	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Hexachloroben zene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Gamma-BHC	3.96	ND	3.96	ND	ND	ND	2.34	ND	2.34	ND	ND	ND	1.07	ND	1.07	3
Beta-BHC	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.05	ND	2.05	1
Chlordene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Delta-BHC	21.86	6.69	28.55	24.75	13.52	38.27	26.50	68.25	94.75	ND	ND	ND	ND	ND	ND	3
Heptachlor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Aldrin	9.47	ND	9.47	8.63	6.35	14.98	17.45	ND	17.45	ND	ND	ND	ND	ND	ND	3
Isodrin	52.36	4.61	56.97	8.20	ND	8.20	3.65	55.30	58.95	ND	ND	ND	ND	ND	ND	3
Heptachlor Epoxide-isomer B	ND	ND	ND	ND	ND	ND	10.43	ND	10.43	ND	ND	ND	5.59	0.72	6.31	2
Gamma-Chlordane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	3.40	ND	3.40	1
Endosulfan I	ND	ND	ND	10.04	ND	10.04	20.93	46.86	67.79	ND	ND	ND	ND	ND	ND	2
Alpha-chlordane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.09	ND	6.09	1
Trans-nonachlor	ND	ND	ND	ND	10.03	10.03	ND	6.38	6.38	ND	ND	ND	ND	ND	ND	2
4,4'-DDE	ND	ND	ND	32.90	ND	32.90	24.51	5.52	30.03	ND	ND	ND	7.97	ND	7.97	3
Dieldrin	47.36	38.15	85.51	49.69	43.11	92.80	67.60	49.73	117.34	2.68	3.03	5.71	13.97	2.42	16.40	5
Endrin	ND	ND	ND	25.31	18.90	44.21	ND	48.89	48.89	ND	ND	ND	ND	ND	ND	2
Endosulfan II	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Chlorobenzilate	ND	12.32	12.32	13.50	16.87	30.37	14.52	21.58	36.10	ND	ND	ND	5.23	ND	5.23	4
Cis-nonachlor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	5.71	ND	5.71	1
4,4'-DDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Endrin aldehyde	ND	ND	ND	27.91	23.62	51.53	ND	21.46	21.46	ND	ND	ND	ND	ND	ND	2

	May-08			Jun-08			Jul-08			Aug-08			Sep-08			No of detect. in samples
	Liquid phase	Solid phase	Total	Liquid phase	Solid phase	Total	Liquid phase	Particle phase	Total	Liquid phase	Solid phase	Total	Liquid phase	Particle phase	Total	
Endosulfan sulfate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
4,4′-DDT	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.06	ND	6.06	1
Endrin ketone	ND	7.98	7.98	1.61	26.20	27.81	18.30	14.40	32.70	ND	ND	ND	ND	ND	ND	3
Methoxychlor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Total organochlorine pesticides	141.86	69.75	211.61	202.54	158.60	361.14	214.34	356.38	570.71	2.68	3.03	8.45	56.08	2.84	59.66	5
Total PCBs (Sum of 27 congeners)	207.48	46.74	254.22	100.21	58.62	158.84	80.08	63.45	143.54	97.07	35.51	132.58	41.66	44.45	86.11	5
Bisphenol A	6.43	15.67	22.10	0.69	18.23	18.92	0.35	29.51	29.86	0.70	0.67	1.37	0.43	56.71	57.14	5
Estrone	1.12	ND	1.12	1.54	2.17	3.71	1.81	ND	1.81	ND	ND	ND	ND	ND	ND	3
17β-Estradiol	ND	3.76	3.76	ND	1.23	1.23	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
17α-Ethinylestradiol	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Total EDCs	356.89	135.92	492.81	304.99	238.85	543.84	296.58	449.34	745.92	100.45	39.21	142.30	98.17	104.00	202.91	5

Table 3

EDC Concentrations (ng L^{-1}) in Lake Pontchartrain water from May 2008 to September 2008

	May-08			Jun-08			Jul-08			Aug-08			Sep-08			No of detect. in samples
	Liquid phase	Solid phase	Total	Liquid phase	Solid phase	Total	Liquid phase	Solid phase	Total	Liquid phase	Solid phase	Total	Liquid phase	Solid phase	Total	
1,2-Dibromo-3-chloropropane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Hexachloropenta diene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Diallate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	2.41	2.41	5.57	12.61	18.18	2
Alpha-BHC	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Hexachloroben zene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Gamma-BHC	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Beta-BHC	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	7.72	7.72	1
Chlordene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	4.65	10.51	15.16	1
Delta-BHC	0.00	27.83	27.83	24.67	12.63	37.30	9.63	13.17	22.80	ND	ND	ND	ND	ND	ND	3
Heptachlor	4.68	0.00	4.68	7.36	ND	7.36	ND	5.98	5.98	ND	ND	ND	ND	ND	ND	3
Aldrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Isodrin	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Heptachlor epoxide-isomer B	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	21.22	21.22	ND	ND	ND	1
Gamma-chlordane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Endosulfan I	17.54	ND	17.54	6.57	21.48	28.05	ND	15.68	15.68	ND	ND	ND	ND	ND	ND	3
Alpha-chlordane	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	27.20	61.51	88.71	1
Trans-nonachlor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	4.02	4.02	ND	ND	ND	1
4,4'-DDE	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Dieldrin	85.37	12.42	97.80	20.82	90.89	111.71	17.23	13.57	30.80	ND	18.02	18.02	ND	ND	ND	4
Endrin	0.00	16.45	16.45	32.09	11.23	43.32	ND	ND	ND	ND	ND	ND	ND	ND	ND	2
Endosulfan II	ND	ND	ND	ND	ND	ND	ND	21.03	21.03	ND	ND	ND	12.69	28.71	41.40	2
Chlorobenzilate	9.53	7.59	17.12	2.74	17.29	20.03	7.83	18.20	26.03	ND	5.53	5.53	ND	ND	ND	4
Cis-nonachlor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
4,4'-DDD	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Endrin aldehyde	14.38	9.87	24.25	49.71	53.99	103.70	49.03	51.27	100.3	ND	10.47	10.47	ND	ND	ND	4

	May-08			Jun-08			Jul-08			Aug-08			Sep-08			No of detect. in samples
	Liquid phase	Solid phase	Total	Liquid phase	Solid phase	Total	Liquid phase	Solid phase	Total	Liquid phase	Solid phase	Total	Liquid phase	Solid phase	Total	
Endosulfan sulfate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
4,4'-DDT	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	6.16	6.16	9.73	22.00	31.72	2
Endrin keton	ND	10.20	10.20	2.68	9.76	12.44	3.25	6.39	9.64	ND	ND	ND	ND	ND	ND	3
Methoxychlor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	0
Total organochlorine pesticides	131.50	84.36	215.86	146.64	217.27	363.91	86.97	145.29	232.26	0.00	67.85	67.85	59.84	143.06	202.90	5
Total PCBs (Sum of 27 congeners)	263.00	168.72	431.72	293.28	434.54	727.82	178.63	290.58	469.21	0.00	133.92	133.92	116.60	263.74	380.34	5
Bisphenol A	20.38	1.71	22.09	12.28	0.32	12.60	5.18	18.66	23.84	3.97	12.69	16.66	14.11	5.84	19.95	5
Estrone	0.00	0.43	0.43	1.90	1.49	3.38	0.83	ND	0.83	ND	ND	ND	ND	ND	ND	3
17β-Estradiol	1.79	ND	1.79	1.91	0.35	2.26	0.41	0.00	0.41	ND	ND	ND	ND	ND	ND	3
17α-Ethinylestradiol	ND	ND	ND	ND	2.10	2.10	ND	2.18	2.18	ND	ND	ND	ND	2.43	2.43	3
Total EDCs	416.66	255.22	671.88	456.00	656.06	1112.23	272.10	456.71	728.81	3.97	214.56	218.42	190.55	415.06	605.62	5

Table 4

Summary of EDC concentrations in Mississippi Sound sediments

EDCs	South of Bay St. Louis (ng g^{-1})			Pearl River Mouth (ng g^{-1})			Henderson Point (ng g^{-1})			Horn Island (ng g^{-1})		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
1,2-Dibromo-3-chloropropane	ND	ND	ND	ND	1.28	0.02	ND	ND	ND	ND	ND	ND
Hexacloropentadiene	ND	4.15	1.04	ND	3.19	0.76	ND	ND	ND	ND	7.82	5.04
Diallate	ND	2.61	0.52	2.50	5.75	3.21	ND	ND	ND	ND	14.63	1.46
Alpha-BHC	0.47	18.19	5.40	6.90	14.22	9.36	0.47	3.54	1.70	4.55	18.80	10.17
Hexachlorobenzene	ND	ND	ND	ND	1.07	0.27	ND	ND	ND	ND	2.37	0.85
Gamma-BHC	ND	ND	ND	ND	ND	ND	ND	154.76	18.92	ND	112.47	16.72
Beta-BHC	ND	11.00	1.22	ND	23.38	2.91	ND	3.41	0.31	ND	139.90	32.69
Chlordene	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Delta-BHC	ND	32.38	4.68	ND	7.78	3.06	ND	85.91	7.81	ND	248.20	64.12
heptachlor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Aldrin	ND	43.32	7.16	ND	52.91	12.77	ND	167.69	25.41	ND	444.05	102.28
Isodrin	ND	ND	ND	ND	175.81	22.58	ND	45.52	17.73	ND	372.82	108.73
Heptachlor epoxide-isomer B	ND	ND	ND	ND	66.84	8.68	ND	ND	ND	ND	85.50	25.75
Gamma-chlordane	ND	13.83	4.12	ND	16.96	6.31	ND	10.94	2.77	ND	29.97	13.36
Endosulfan I	54.79	235.30	108.33	26.93	397.06	151.33	ND	45.24	10.01	ND	375.35	37.54
Alpha-chlordane	ND	ND	ND	ND	ND	ND	ND	9.10	0.83	ND	ND	ND
Trans-nonachlor	ND	ND	ND	ND	35.67	4.57	ND	ND	ND	ND	36.79	8.29
4,4'-DDE	ND	3.90	0.43	ND	111.69	24.15	ND	ND	ND	ND	63.30	6.33
Dieldrin	ND	88.08	15.93	79.84	118.26	87.96	ND	73.77	44.07	ND	92.36	71.59
Endrin	ND	310.49	81.54	ND	413.58	164.71	ND	102.51	15.72	ND	322.89	103.91
Endosulfan II	ND	ND	ND	ND	ND	ND	ND	8.10	0.74	ND	156.52	29.70
Chlorobenzilate	ND	19.89	2.21	ND	191.25	34.65	ND	80.06	8.67	ND	204.86	54.21
Cis-nonachlor	ND	ND	ND	ND	18.57	0.23	ND	ND	ND	ND	13.25	2.32
4,4'-DDD	ND	ND	ND	ND	16.34	0.20	ND	ND	0.00	ND	25.27	4.71
Endrin aldehyde	ND	179.38	19.93	47.22	159.74	87.28	ND	13.57	2.44	ND	169.06	43.08
Endosulfan sulfate	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
4,4'-DDT	ND	ND	ND	ND	98.50	1.22	ND	200.15	26.81	ND	339.72	110.03

EDCs	South of Bay St. Louis (ng g^{-1})			Pearl River Mouth (ng g^{-1})			Henderson Point (ng g^{-1})			Horn Island (ng g^{-1})		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Endrin ketone	ND	243.74	9.82	68.91	867.08	277.44	ND	271.14	24.84	6.00	737.99	302.02
Methoxychlor	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND	ND
Total OCPs	55.26	1206.26	262.33	232.3	2796.93	903.67	0.47	1275.41	208.78	10.55	4013.89	1154.90
Total PCBs	ND	5.95	3.42	2.17	6.86	3.59	ND	5.35	3.38	2.46	31.74	9.29
Bisphenol A	ND	1.75	0.71	ND	1.51	0.40	ND	1.03	0.38	0.53	2.99	1.33
Estrone	ND	0.44	0.19	ND	ND	ND	ND	0.33	0.06	ND	0.59	0.32
17β-Estradiol	ND	0.05	ND	ND	ND	ND	ND	0.34	0.04	ND	2.63	0.50
17α-Ethinylestradiol	ND	0.45	0.18	ND	0.25	0.14	ND	0.15	0.08	ND	0.20	0.11
Total EDCs	55.26	1214.9	266.83	234.47	2805.55	907.8	0.47	1282.46	212.72	13.54	4052.04	1166.45

Table 5

EDC Concentrations (ng L^{-1}) in New Orleans sewage influent and effluent

	Sewage Influent			Sewage Effluent			
	Liquid phase	Particle phase	Total	Liquid phase	Particle phase	Total	% Removal
Total organochlorine pesticides (Sum of 29 OCP$_3$)	427.57	532.67	960.25	311.00	313.69	624.69	35
Total PCBs (Sum of 27 congeners)	10.22	53.76	63.98	11.48	19.16	30.64	52
Bisphenol A	203.01	131.04	334.05	44.89	10.23	55.12	84
Estrone	167.3	191.69	358.99	72.73	39.14	111.87	69
17β-Estradiol	61.61	93.86	155.47	18.97	35.9	54.87	65
17α-Ethinylestradiol	1.89	2.70	4.59	2.06	3.11	5.17	0
Total EDCs	888.61	1005.72	1877.33	461.13	421.23	882.36	53